CLUMP STARS IN THE SOLAR NEIGHBOURHOOD

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Abstract: *Hipparcos* data has allowed the identification of a large number of clump stars in the Solar Neighbourhood. We discuss our present knowledge about their distributions of masses, ages, colours, magnitudes, and metallicities. We point out that the age distribution of clump stars is "biased" towards intermediate-ages. Therefore, the metallicity information they contain is different from that provided by the local G dwarfs. Since accurate abundance determinations are about to become available, these may provide useful constraints to chemical evolution models of the local disc.

1. The clump after *Hipparcos*

The clump of core-helium burning stars has been known for decades in the colour-magnitude diagrams (CMD) of open clusters and nearby galaxies. However, only recently we have been able to identify a significant number of clump stars in the Solar Neighbourhood, thanks to the *Hipparcos* mission (Perryman et al. 1997). In fact, the ESA (1997) catalog contains ~ 600 clump stars with parallax error lower than 10 %, and hence an error in absolute magnitude lower than 0.12 mag. This accuracy limit corresponds to a distance of ~ 125 pc within which the sample of clump stars is complete. Moreover, accurate BV photometry (and I for $\sim 1/3$ of the sample), is available, and interstellar absorption is small enough to be neglected.

The *Hipparcos* M_V versus $B-V$ CMD is illustrated on the left panel of Fig. 1. In this plot, we exclude binaries and limit the sample to stars with $\pi < 0.007$ arcsec and $V < 8.5$. The clump is well evident at $M_V \simeq 1$, $B-V \simeq 1$.

So far, most of the emphasis on nearby clump stars has been on their possible use as standard candles, since their mean absolute magnitude can be determined with an accuracy of hundredths of magnitude from *Hipparcos* database (cf. Paczyński & Stanek 1998; Stanek et al. 1998). This application requires a good understanding of the basic characteristics of clump stars, in

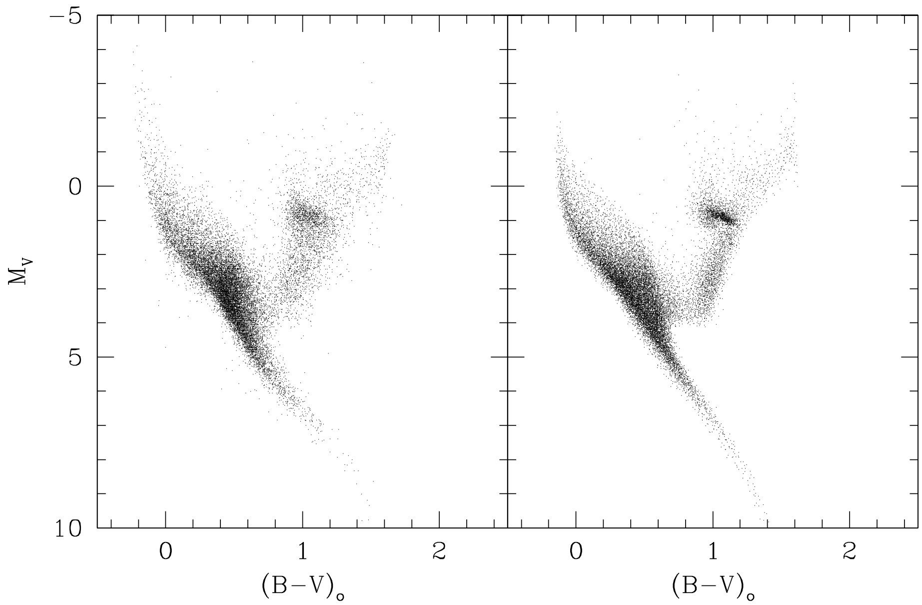

Figure 1. Left panel: *Hipparcos* data. Right panel: theoretical simulation (see text).

order to access the systematic changes of the clump luminosity in different populations, as those pointed out by Cole (1998) and Girardi et al. (1998).

2. The mass distribution

A common idea is that the mass distribution of clump stars roughly follows the IMF, presenting then a single and sharp peak at the lowest possible masses, i.e. with $0.8 - 1.2\ M_{\odot}$. This reasoning, however, is not valid for evolved stars such as core-helium burners. From simple arguments we can derive their mass distribution, in a galaxy of age T, as being proportional to the IMF ϕ_M, to the core-helium burning lifetime $t_{\rm He}$, and to the star formation rate (SFR) at the epoch of birth $\psi[T - t(M)]$. Since $t_{\rm He}$ presents a peak at about $2\ M_{\odot}$ (the transition from low- to intermediate masses), and the IMF shows a peak at the lowest masses, a *double-peaked mass distribution* appears (Girardi 1999). This is shown at the left panel of Fig. 2, for the case of a constant SFR from 0.1 to 10 Gyr ago, and a Salpeter IMF.

Moreover, it turns out that some intermediate-mass stars, from say 2 to 2.5 $M_{\odot}$, are not severely under-represented with respect to the low-mass ones. They are close enough to the clump region in the CMD to be considered as genuine clump stars. For the case of a constant SFR, they make about 20 % of the clump.

However, is the hypothesis of a constant SFR a realistic one for the

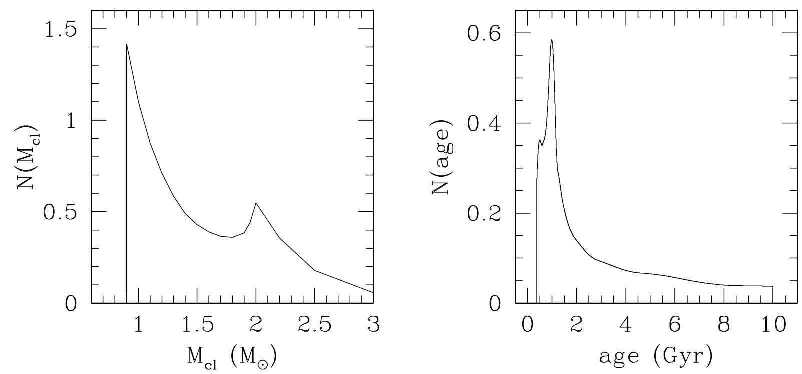

Figure 2. Mass (left panel) and age (right panel) distribution of clump stars for the case of a constant star formation rate (see text).

local disc ? From careful analyses of the *Hipparcos* CMD, Bertelli & Nasi (1999) favour an almost-constant SFR with *increasing* rates in the last few Gyr, whereas Gilmore et al. (this meeting) find several episodes of star formation, without any marked long-term trend of decreasing or increasing SFR. An independent indication for a roughly-constant SFR (over time-scales of several Gyr) comes from the simulation we present in the right panel of Fig. 1. Using a population synthesis code, we generate an uniform distribution of stars, and limit it to $\pi < 0.007$ arcsec and $V < 8.5$. The stars are picked up from the Girardi et al. (2000) set of evolutionary tracks and isochrones, and distributed according to a constant SFR and with a metallicity distribution $[\mathrm{Fe/H}] = -0.12 \pm 0.18$ (see § 6 below). Although this was intended to be a *crude* initial model for the local stars, the derived synthetic CMD reproduces quite well the observed number of stars in several key regions of the *Hipparcos* CMD (Girardi et al., in preparation).

3. The age distribution

A constant SFR does not mean a constant age distribution, at least not for evolved stars. In fact, from the mass distribution of clump stars obtained with a constant SFR, we can easily derive the age distribution shown in the right panel of Fig. 2. The latter is far from being constant; it peaks at an age of 1 Gyr, and decreases monotonically afterwards. Half of the clump stars have ages lower than 2 Gyr ! This result comes, essentially, from the continuous decrease, with age, of the birth rate of post-main sequence stars.

Therefore, the age distribution of clump stars (K giants) is very different from that of low-main sequence stars (G dwarfs). The long-lived G dwarfs have an age distribution simply proportional to the SFR, whereas K giants have it "biased" towards intermediate-ages ($1-3$ Gyr). This difference

reflects also into the metallicities: since younger stars are more metal rich, giants tend to have a relatively narrow metallicity distribution, if compared to dwarfs (see § 6 below).

These results are in contrast with a common prejudice, i.e. that red giants sample equally well stellar populations of all ages, from the intermediate-age (metal rich) to the oldest (metal-poor) ones in a galaxy. This is not the case. Only in galaxies which formed few stars at intermediate-ages, can the age distribution of red giants be expected to be moderately flat.

4. The colour distribution

Red giant stars are known to become redder at higher metallicities. Jimenez et al. (1998) applied this concept to derive, solely from the colour range of *Hipparcos* clump stars, an estimate of metallicity range covered by them, obtaining $-0.7 < [\mathrm{Fe/H}] < 0.0$. Although this result has little effect on their estimate of the age of the Galactic disc (Carraro, this meeting), the approach is essentially misleading. In fact, red giants become redder also at lower masses, or equivalently, at higher ages. Girardi et al. (1998) demonstrated that a galaxy model with mean solar metallicity, a *very small* metallicity dispersion ($\sigma_{[\mathrm{Fe/H}]} = 0.1$ dex), and constant SFR up to 10 Gyr ago, shows a clump as wide in colour as the observed *Hipparcos* one – i.e. with $\Delta(V-I) \simeq 0.2$ mag (see also Fig. 1). It follows that a significant fraction of the colour spread of the local clump might be due to an age spread, rather than to a metallicity spread.

5. The magnitude distribution

The correct interpretation of the colour spread of clump stars is also crucial for distance determinations. Were the clump colour determined by metallicity only, the observed constancy of the I-band magnitude with colour inside the clump, in different galaxies, would be indicating that M_I is virtually independent of metallicity, and hence an excelent standard candle (cf. Paczyński & Stanek 1998; Stanek et al. 1998; Udalski 1998a).

This conclusion is not supported by theoretical models (Cole 1998; Girardi et al. 1998), which predict a brighter clump at lower metallicities, and a more complex dependence on age. The observational works by Udalski (1998a,b), instead, conclude for a very modest dependence of M_I on both metallicity and age. However, the data analyses contain several uncertain assumptions, like the large "geometric corrections" applied to the distances of LMC and SMC clusters in Udalski's (1998b) study. More recently, Twarog et al. (1999) and Sarajedini (1999) concluded for a larger age and metallicity dependence of the clump magnitude, using data from disc open clusters.

Models predict that the clump magnitude depends on age in a non-

monotonic way, being fainter than the mean (by up to 0.4 mag) at both the ~ 1 Gyr and $\gtrsim 10$ Gyr age intervals. These two groups with the lowest luminosities correspond also to the bluest and reddest clump stars one finds for a given metallicity. The effect is such that, summing up stars of all ages, one can easily obtain a nearly-horizontal clump in the M_I versus $V-I$ CMD, similar to the *Hipparcos* one (Girardi et al. 1998). Almost-horizontal structures can also be obtained in galaxy models with decreasing SFRs and a reasonable age-metallicity relation (cf. Girardi 1999). Thus, the observed constancy of M_I with colour in the clump of different galaxies can be reasonably reproduced by models. Nonetheles, there is no reason for M_I being constant from galaxy to galaxy. In fact, the LMC clump should be intrinsically brighter than the local one by $0.2-0.3$ mag in the I-band (Cole 1998; Girardi et al. 1998).

A fine structure in the CMD – namely a fainter secondary clump plus a low-density bright plume – comes out in galaxy models containing $\sim$ 1-Gyr old populations with metallicities $Z \gtrsim 0.004$ (Girardi et al. 1998; Girardi 1999). These features are due to the intermediate-mass clump stars, i.e. those just massive enough for starting to burn helium in non-degenerate conditions. A nice confirmation of the predictions is provided by Bica et al. (1998) and Piatti et al. (1999), who detected a group of faint clump stars in several fields over the LMC. Similar structures are also present in the *Hipparcos* CMD (Girardi et al. 1998; Beaulieau & Sackett 1998).

6. The metallicity distribution

The metallicities of 581 nearby K giants (mainly clump stars) have been derived by Høg & Flynn (1998), based on DDO photometry. From their data it turns out that the $V-I$ colour does not correlate with [Fe/H] (cf. Paczyński 1998), contrarily to what expected, for intance, from Jimenez et al. (1998) analysis of local clump stars. On the basis of the arguments discussed in § 4 above, however, this result is not surprising: it might simply reflect that the colour spread of the local clump is mostly due to an age spread (from ~ 1 to 10 Gyr), rather than due to a metallicity spread.

Girardi & Salaris (in preparation) selected a sample of clump stars with spectroscopic abundance determinations. The resulting metallicity distribution is Gaussian-like with a very small dispersion, i.e. $[\mathrm{Fe/H}] = -0.12 \pm 0.18$ dex. This disagrees with the metallicity range ($-0.7 \leq [\mathrm{Fe/H}] \leq 0.0$) derived from the colours by Jimenez et al. (1998). Again, the spectroscopic [Fe/H] determinations indicate that the colour spread in the local clump cannot be simply due to a spread of metallicity.

Another evident aspect in the metallicity distribution of clump stars is the anallogous of the G-dwarf problem: only 15 out of 334 clump stars have $[\mathrm{Fe/H}] < -0.5$, whereas *at least* 43 are expected from a simple closed-box

model of chemical evolution. This new "K-giant problem" is quantitatively different from the G-dwarf one, since it is offered by stars which are, on the mean, younger than G dwarfs. Therefore, the chemical information provided by clump stars should be considered as additional to that provided by the dwarfs, and more suitable to probe the chemical conditions at intermediate-ages (from say 1 to 4 Gyr ago).

7. Concluding remarks

The *Hipparcos* catalog provides us an extremely interesting sample of clump stars, complete up to 125 pc, and representing a well-understood evolutionary stage. Thus far, it has provided interesting checks to the theory of stellar evolution and population synthesis. A good example is the finding of a fine structure in the clump, which represents a sort of "lower main sequence" for core-helium burning stars. Theoretical modelling of the clump in galaxies also brings some unexpected results, such as the wide and double-peaked mass distribution, and the intrinsic bias towards intermediate-ages. These aspects should be taken into account when interpreting the observational data related to clump stars, and to red giants in general.

The perspectives of using the clump data for probing the chemical evolution of the Galactic disc are also very promising. Grenon and Morossi (both in this meeting) announced more reliable and homogeneous chemical abundance determinations for nearby red giants. With these new data, the sample of nearby clump stars may render additional (and quantitative) constraints to chemical evolution models of the Solar Neighbourhood. In this respect, we should also consider the tight constraints to the disc SFR provided by the detailed analyses of the *Hipparcos* CMD.

References

1. Beaulieu J.-P., Sackett P.D., 1998, AJ 116, 209
2. Bertelli G., Nasi E., 1999, A&A in press
3. Bica E., Geisler D., Dottori H., et al., 1998, AJ 116, 723
4. Cole A.A., 1998, ApJ 500, L137
5. ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200
6. Girardi L., Groenewegen M.A.T., Weiss A., Salaris M., 1998, MNRAS 301, 149
7. Girardi L., 1999, MNRAS 308, 818
8. Girardi L., Bressan A., Bertelli G., Chiosi C., 2000, A&AS in press
9. Høg E., Flynn C., 1998, MNRAS 294, 28
10. Jimenez R., Flynn C., Kotoneva E., 1998, MNRAS 299, 515
11. Paczyński B., 1998, Acta Ast. 48, 405
12. Paczyński B., Stanek K.Z., 1998, ApJ 494, L219
13. Perryman M.A.C., Lindegren L., Kovalevsky J., et al., 1997, A&A 323, L49
14. Piatti A., Geisler D., Bica E., et al., 1999, AJ in press (astro-ph/9909475)
15. Sarajedini A., 1999, AJ in press
16. Stanek K.Z., Zaritsky D., Harris J., 1998, ApJ 500, L141
17. Udalski A., 1998a, Acta Astr. 48, 113
18. Udalski A., 1998b, Acta Astr. 48, 383